

National Aeronautics and Space Administration



Laser Reliability Final Report

Dr. Ivair Gontijo
Dr. Andrew A. Shapiro
Daniel T. Fuller

Jet Propulsion Laboratory
Pasadena, CA

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL Publication 09-12 3/09



Laser Reliability Final Report

NASA Electronic Parts and Packaging (NEPP) Program
Office of Safety and Mission Assurance

Dr. Ivair Gontijo
Dr. Andrew A. Shapiro
Daniel T. Fuller

Jet Propulsion Laboratory
Pasadena, CA

NASA WBS:
JPL Project Number: 102197
Task Number: 2.32.6

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

<http://nepp.nasa.gov>

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the National Aeronautics and Space Administration Electronic Parts and Packaging (NEPP) Program.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

Copyright 2009. California Institute of Technology. Government sponsorship acknowledged.

Table of Contents

| | |
|-------------------------|---|
| Executive Summary | 1 |
| 1 Introduction..... | 1 |
| 2 Objectives | 1 |
| 3 Deliverables | 1 |
| 4 Conclusion | 9 |

Executive Summary

This is the final report of the Laser Diode and Diode Array Reliability Project, in which a semiconductor laser reliability study was performed. A list of lasers in use at the Jet Propulsion Laboratory (JPL) was created to identify wavelengths and power levels of interest. A design of experiments was created as a template for laser testing for reliability. During this project, a laser laboratory for reliability studies was set up and software was written in Labview to control the experiments. This set-up is now in use by other groups at JPL, including the Nustar project. Failure analysis of a failed laser was conducted and a conference paper presented at the Electronic Systems and Technology Integration Conference 2008 (ESTC2008).

1 Introduction

Present laser diodes and laser diode arrays have significant reliability issues. A number of failures have been reported; most significantly, the space-flight failures on GLASS and IceSAT have cost the National Aeronautics and Space Administration (NASA) tremendously in terms of science and dollars. The failure modes are due to a combination of problems with the reliability of the devices as well as the reliability of the packaging. The two are intimately related in a number of ways. The packaging, with these high-powered systems, controls the device temperature (which in effect controls the device reliability), but in addition to this, there are a number of packaging failure modes as well as packaging-process related failure modes that are also relevant and not well quantified. In addition, the limited data provided by various vendors are not consistent due to a lack of standardization in testing and reporting. Often data are reported as a number of shots (at an arbitrary power level), FIT, and total hours (again at an arbitrary power).

2 Objectives

The objectives of this project were to:

1. Characterize a relevant set of laser diodes and diode arrays with a standardized test set-up (coordinated with other NASA centers) and create a trade-space so that differing vendor data may be compared
2. Identify key device, package, and process-related failure modes
3. Provide the outline of a standard set of guidelines for the testing and reliability reporting of laser diodes and laser diode arrays

3 Deliverables

This project produced a set of deliverables and reports, which were submitted for clearance. Two of the reports were cleared and the others are still in-process. Some of the reports and papers produced include:

- Initial Data FY07.doc
- Acquisition of New Laser FY07.doc
- Design of Experiment FY06.doc

- Test Set-up FY06.doc
- Reliability of Semiconductor Laser Packaging in Space Applications—paper presented at the ESTC2008.

Physical deliverables produced in this project were:

- Software to control up to eight lasers and temperature controllers, specifically written for this application
- Laser lab set-up for lifetime testing of up to six lasers

Figures 1–3 and Table 1 show some of the test data collected and other details of the deliverables in this project.

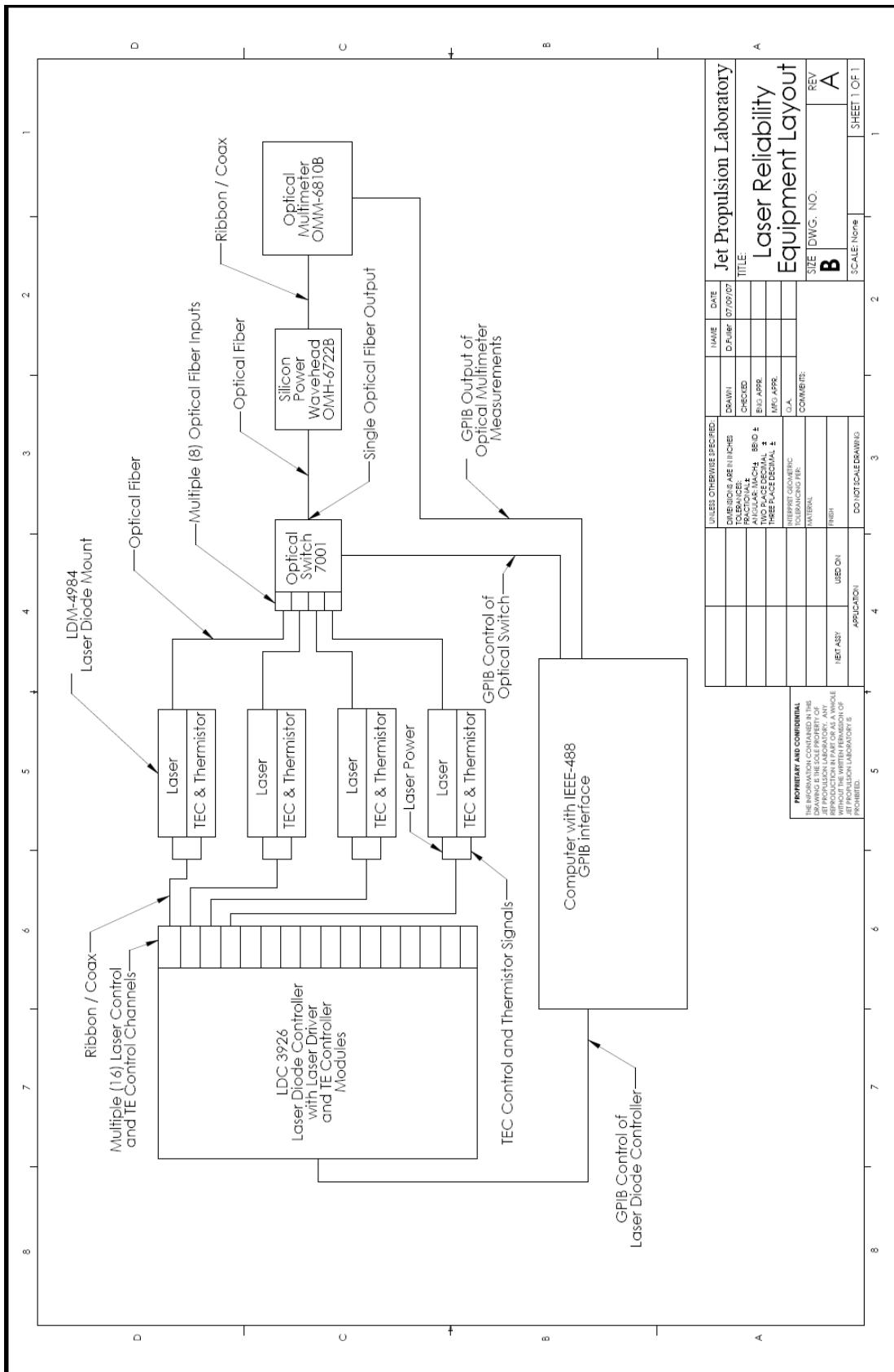


Figure 1. Typical Set-up for Laser Reliability Study

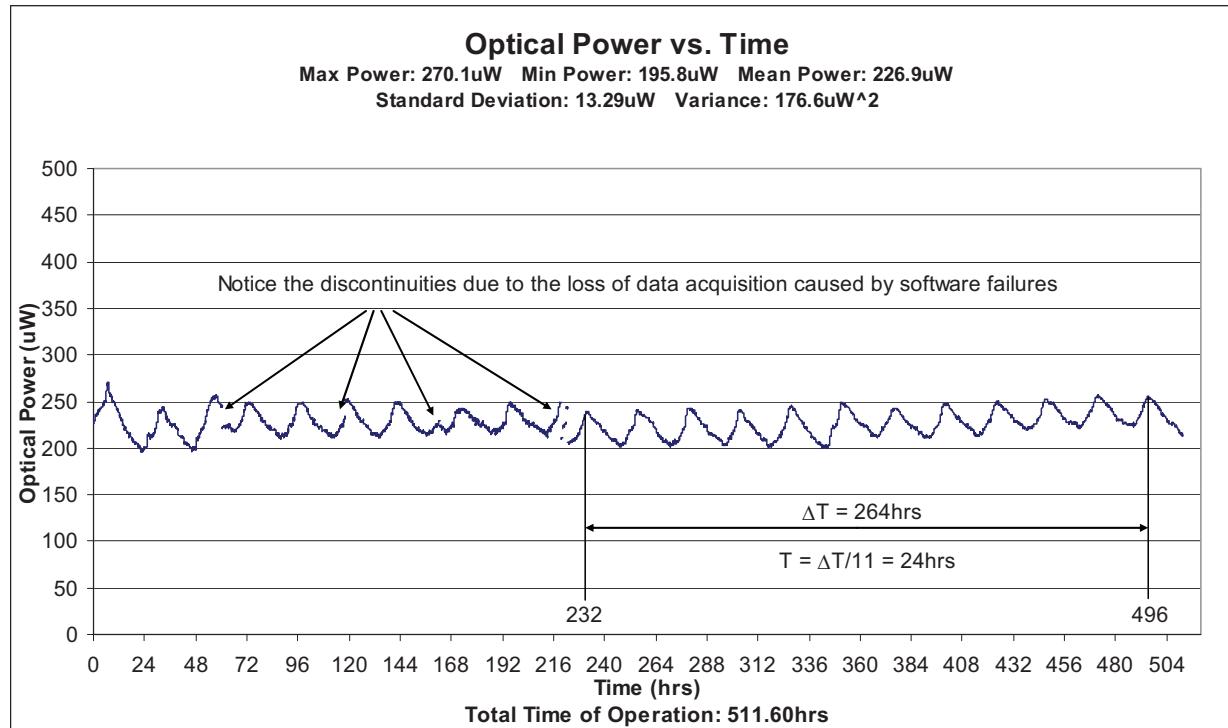


Figure 2. Laser Lifetime Test Results—Optical Output Power

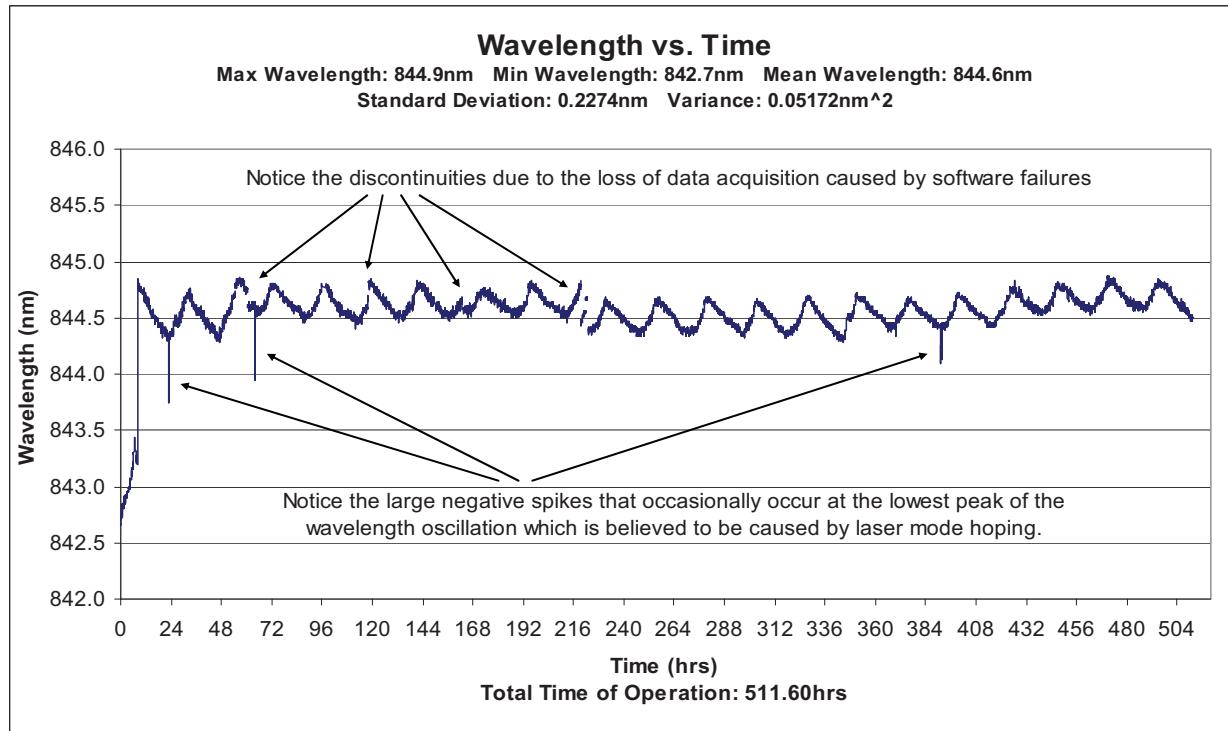


Figure 3. Laser Lifetime Test Results—Laser Wavelength x Time

Table 1. JPL Laser Inventory

| Section | Laser Mfc | Lasing Media/Type | Power (Class) | Wavelength | Quantity | Status Active or Stored |
|---------|--------------------------|-------------------|---------------|--------------|----------|-------------------------|
| 323 | Thor Labs | Diode | Class IIIa | 1.37 nm | 1 | Active |
| 323 | Thor Labs | Diode | Class IIIa | 1.88 nm | 1 | Active |
| 322 | Power Technology | Diode | Class IIIB | 405 nm | 1 | Active |
| 383 | QED | Diode | Class IIIB | 532 nm | 2 | Active |
| 383 | Edmund Industrial Optics | Diode | Class IIIa | 634 nm | 1 | Active |
| 383 | Edmund Industrial Optics | Diode | Class II | 635 nm | 1 | Active |
| 383 | Thor Labs | Diode | Class IIIB | 635 nm | 2 | Active |
| 323 | Coherent | Diode | Class IIIb | 635 nm | 2 | Active |
| 332 | Thorlabs | Diode | Class IIIa | 653 nm | 1 | Active |
| 332 | Handmade by Savchenkov | Diode | Class IIIa | 653 nm | 1 | Active |
| 383 | Wave Optics | Diode | Class IIIa | 635 nm | 2 | Active |
| 383 | Melles Griot | Diode | Class IIIB | 660 nm | 1 | Active |
| 335 | New Focus | Diode | Class IIIB | 778 nm | 1 | Active |
| 347 | Acuity | Diode | Class IIIB | 780 nm | 4 | Stored |
| 332 | Axcel Photonics, Inc | Diode | Class IIIB | 780 nm | 2 | Active |
| 332 | Vortex | Diode | Class IIIB | 780 nm | 1 | Active |
| 383 | Newport | Diode | Class IIIa | 785 nm | 1 | Active |
| 383 | Thor Labs | Diode | Class IIIB | 785 nm | 2 | Active |
| 332 | High Power Devices | Diode | Class IV | 801 nm | 1 | Active |
| 332 | Coherent | Diode | Class IIIB | 808 nm | 1 | Active |
| 324 | Coherent | Diode | Class IV | 808 nm | 1 | Active |
| 346 | JPL | Diode | Class IV | 808 nm | 1 | Active |
| 332 | High Power Devices | Diode | Class IV | 819 nm | 1 | Active |
| 383 | Thor Labs | Diode | Class IIIB | 830 nm | 2 | Active |
| 332 | Axcel Photonics, Inc | Diode | Class IIIB | 830 nm | 2 | Active |
| 324 | New Focus | Diode | Class IIIB | 835 nm | 2 | Stored |
| 383 | Newport | Diode | Class IIIB | 836.5 nm | 1 | Active |
| 335 | New Focus | Diode | Class IIIB | 852 nm | 11 | Active |
| 335 | SDL/JDS Uniphase | Diode | Class IIIB | 852 nm | 3 | Active |
| 332 | SDL | Diode | Class IV | 972 nm | 1 | Stored |
| 346 | Pirelli | Diode | Class IIIB | 980 nm | 1 | Active |
| 332 | Axcel Photonics, Inc | Diode | Class IIIB | 980 nm | 3 | Active |
| 383 | B & W Tech | Diode | Class IIIB | 980 nm | 1 | Active |
| 324 | New Focus | Diode | Class IIIB | 1401-1481 nm | 1 | Stored |
| 324 | JPL Microdevices Lab | Diode | Class IIIa | 1480-1520 nm | 1 | Active |
| 324 | New Focus | Diode | Class IIIa | 1510-1590 nm | 1 | Stored |
| 324 | New Focus | Diode | Class IIIB | 1518-1572 nm | 1 | Stored |
| 324 | New Focus | Diode | Class IIIB | 1534 nm | 1 | Stored |
| 324 | New Focus | Diode | Class IIIB | 1550-1630 nm | 1 | Active |
| 324 | Sacher Laser | Diode | Class IIIB | 1600-1670 nm | 1 | Active |
| 322 | JPL | Diode | Class IIIB | 1870 nm | 1 | Active |
| 3227 | Laser Components, Inc | Diode | Class IIIB | 6700 nm | 4 | Active |
| 332 | Boston Laser x 4 | AlGaAs/Diode | Class IV | 808 nm | 1 | Stored |
| 332 | Thorlabs | GaAs/Diode | Class IIIB | 635 nm | 1 | Stored |
| 332 | Melles Griot | GaAs/Diode | Class IIIB | 780 nm | 1 | Stored |

| Section | Laser Mfc | Lasing Media/Type | Power (Class) | Wavelength | Quantity | Status Active or Stored |
|---------|----------------------|-----------------------|---------------|--------------|----------|-------------------------|
| 332 | SDL | GaAs/Diode | Class IIIB | 780 nm | 1 | Stored |
| 332 | Coherent X 8 | GaAs/Diode | Class IV | 808 nm | 1 | Stored |
| 332 | SDL x 4 | GaAs/Diode | Class IV | 808 nm | 1 | Stored |
| 332 | JPL (OCD) | GaAs/Diode | Class IIIB | 840 nm | 1 | Stored |
| 332 | SDL x4 | GaAs/Diode | Class IIIB | 840 nm | 1 | Stored |
| 332 | Axcel Photonics, Inc | GaAs/Diode | Class IIIB | 980 nm | 1 | Stored |
| 332 | Thorlabs | InGaAs/Diode | Class IIIB | 980 nm | 1 | Stored |
| 332 | Lumics | InGaAs/Diode | Class IIIB | 1060 nm | 1 | Stored |
| 332 | Qphotonics | InGaAs/Diode | Class IIIB | 1064 nm | 1 | Stored |
| 332 | OCP | InGaAs/ Diode | Class II | 1550 nm | 1 | Stored |
| 332 | JDS | InGaAs/Diode | Class IIIB | 1550 nm | 1 | Stored |
| 332 | Broadata | InGaAs/Diode | Class IIIB | 1550 nm | 1 | Stored |
| 332 | COS | InGaAs/Diode | Class IIIB | 1550 nm | 1 | Stored |
| 332 | OCP | InGaAs/Diode | Class IIIB | 1550 nm | 1 | Stored |
| 332 | Sumitomo | InGaAs/Diode | Class IIIB | 1550 nm | 1 | Stored |
| 332 | Honeywell X 30 | GaAs/VCSEL | Class IIIa | 840 nm | 1 | Stored |
| 332 | Emcore x 20 | GaAs/VCSEL | Class IIIa | 840 nm | 1 | Stored |
| 384 | Toptica | Diode Optical Amp | Class IV | 765-795 nm | 1 | Active |
| 384 | Toptica | Diode Optical Amp | Class IV | 830-870 nm | 1 | Active |
| 332 | Power Technology | Diode/ Free Space | Class IIIB | 980 nm | 1 | Stored |
| 324 | Spectra Physics | Diode pumped vanadate | Class IV | 532 nm | 1 | Active |
| 332 | Alpec-Team | Diode/Laser Pointer | Class IIIB | 630-680 nm | 1 | Stored |
| 343 | NanoLase | Diode pumped | Class IIIB | 1064 nm | 1 | Active |
| 332 | New Focus | External Cavity Diode | Class IIIB | 780 nm | 2 | Active |
| 384 | Bookham/New Focus | External Cavity Diode | Class IIIB | 783 nm | 1 | Active |
| 332 | New Focus | External Cavity Diode | Class IIIB | 795 nm | 2 | Active |
| 384 | Bookham/New Focus | External Cavity Diode | Class IIIB | 832 nm | 1 | Active |
| 332 | New Focus | External Cavity Diode | Class IIIB | 1560 nm | 1 | Active |
| 332 | Thor Labs | Diode/ Fiber Coupled | Class IIIa | 635 nm | 1 | Active |
| 332 | Q Photonics | Diode/ Fiber Coupled | Class IIIa | 1064 nm | 1 | Stored |
| 332 | Q Photonics | Diode/ Fiber Coupled | Class IIIB | 1064 nm | 2 | Active |
| 332 | Lightwave | Diode/ Fiber Coupled | Class IIIB | 1534 nm | 1 | Active |
| 332 | Ortel | Diode/ Fiber Coupled | Class IIIB | 1550 nm | 1 | Active |
| 332 | Fitel | DFB Diode | Class IIIB | 1551-1568 nm | 2 | Stored |
| 346 | SDL | DFB | Class IIIB | 1310 nm | 3 | Active |
| 333 | Ortel | DFB | Class IIIB | 1330 nm | 9 | Active |
| 333 | Ortel | DFB | Class IIIB | 7330 nm | 1 | Active |
| 383 | New Focus | Semiconductor Tunable | Class IIIa | 664-681 nm | 1 | Active |
| 384 | Melles Griot/ Nikon | GaN solid state laser | Class IIIB | 404 nm | 1 | Active |
| 332 | Custom | Solid State | Class IV | 1064 nm | 1 | Active |

| Section | Laser Mfc | Lasing Media/Type | Power (Class) | Wavelength | Quantity | Status Active or Stored |
|---------|------------------------------|----------------------------|---------------|----------------|----------|-------------------------|
| 324 | Tui Optics/Toptica Photonics | Semiconductor | Class IIIa | 832-836 nm | 1 | Stored |
| 514 | Picoquant | Semiconductor | Class II | 975 nm | 1 | Active |
| 514 | Alphalas | Semiconductor | Class IIIB | 1064 nm | 1 | Active |
| 333 | Mitsubishi | Semiconductor | Class IIIB | 1310 nm | 3 | Active |
| 346 | Iolon | Semiconductor | Class IIIB | 1520-1570 nm | 2 | Active |
| 346 | DFB laser from JDSU | Semiconductor | Class IIIB | 1570 nm | 2 | Active |
| 382 | Thor Labs | GaAlAs | Class IIIB | 306-227 nm | 2 | Active |
| 332 | New Focus | AlGaAs | Class IIIB | 840 nm | 1 | Stored |
| 332 | Apollo | GaAs | Class IV | 808 nm | 1 | Stored |
| 333 | Encore | InGaAsP | Class IIIB | 1310 nm | 1 | Stored |
| 324 | IPG Photonics | Fiber Amplifier | Class IIIB | 1530-1570 nm | 1 | Stored |
| 332 | IPG Photonics | Fiber Amplifier | Class IV | 1551-1568 nm | 1 | Active |
| 324 | IPG Photonics | Fiber Amplifier | Class IIIB | 1570-1610 nm | 1 | Stored |
| 332 | JDS | Semiconductor/Fiber | Class IIIB | 976 nm | 1 | Stored |
| 514 | SP Millenium Pro | Laser Diode pumped Nd:YVO4 | Class IV | 532 nm | 1 | Active |
| 332 | SDL | Yb/Fiber | Class IV | 1060 nm | 1 | Stored |
| 332 | IPG | Yb/Fiber | Class IV | 1060 nm | 1 | Stored |
| 332 | Keopsys | Yb/Fiber | Class IV | 1060 nm | 1 | Stored |
| 332 | HRL | Yb/Fiber | Class IV | 1060 nm | 1 | Active |
| 332 | NP Photonics | Fiber | Class IIIB | 1064 nm | 1 | Active |
| 332 | Keopsys | Yb/Fiber | Class IIIB | 1064 nm | 1 | Active |
| 332 | IPG | Yb/Fiber | Class IV | 1064 nm | 1 | Active |
| 332 | CTI | YAG/Yb Fiber | Class IV | 1064 nm | 1 | Active |
| 384 | Orbits Lightwave | Eradium-doped fiber | Class IIIB | 1150 nm | 1 | Active |
| 333 | Ortel | Optical fiber/DFB | Class IIIB | 1300 nm | 2 | Stored |
| 332 | IPG | Er/Fiber | Class IV | 1550 nm | 1 | Stored |
| 332 | IPG | Er/Fiber | Class IV | 1550 nm | 1 | Stored |
| 346 | NP Photonics | Fiber | Class IIIB | 1570 nm | 1 | Active |
| 382 | Melles Griot | Argon/Krypton Ion | Class IIIB | 0.476-0.676 nm | 1 | Active |
| 383 | MPB Technologies | C02 | Class IV | 10.6 nm | 1 | Active |
| 322 | Photon Systems | NeAg/Hollow Cathode | Class IIIB | 224 nm | 5 | Active |
| 324 | Lambda Physik | XeCl/Pulsed | Class IV | 308 nm | 6 | Active |
| 514 | PRA | N2 | 2.5uJ | 380 nm | 1 | Stored |
| 326 | Coherent | Argon | Class IV | 488 nm | 1 | Active |
| 345 | LEXEL LASER, INC | Argon | Class IV | 488-514 nm | 1 | Active |
| 345 | Spectra Physics | argon | Class IV | 488-514 nm | 2 | Stored |
| 384 | Spectra Physics | Argon | Class IV | 514.5 nm | 1 | Active |
| 383 | Argon Gas | Argon Gas | Class IIIB | 514 nm | 1 | Stored |
| 345 | COHERENT | Argon | Class IV | 532 nm | 1 | Active |
| 383 | Lightwave | IR | Class IIIa | 1319 nm | 1 | Stored |
| 383 | Lightwave | IR | Class IIIB | 1319 nm | 4 | Active |
| 324 | Apollo | CO2 gas | Class IV | 10000 nm | 1 | Active |
| 324 | DeMaria Electrooptics(DeOS) | CO2 gas | Class IV | 10000 nm | 1 | Active |

| Section | Laser Mfc | Lasing Media/Type | Power (Class) | Wavelength | Quantity | Status Active or Stored |
|---------|-------------------------------|--|---------------|-----------------|----------|-------------------------|
| 383 | Access Laser Co | C02 | Class IIIB | 10600 nm | 2 | Active |
| 332 | Coherent-DEOS | Carbon Dioxide | Class IV | 10600 nm | 1 | Active |
| 324 | JPL | Methanol gas | Class IV | 75000-500000 nm | 1 | Active |
| 346 | Melles Griot | HeNe gas | Class II | .633 nm | 1 | Active |
| 384 | Research Electro-Optics (REO) | HeNe | Class IIIB | 1.15 & 3.39 nm | 1 | Active |
| 332 | Melles Griot | HeNe/ Self contained tube | Class IIIB | 543.5 nm | 1 | Stored |
| 323 | Melles Griot | HeNe | Class IIIa | 632 nm | 1 | Active |
| 346 | Spectra Physics | HeNe | Class IIIa | 632 nm | 1 | Active |
| 322 | Melles Griot | HeNe | Class IIIB | 632 nm | 2 | Active |
| 345 | Spectra Physics | HeNe | Class IIIB | 632 nm | 2 | Active |
| 384 | Polaris Systems | HeNe | Class II | 632.8 nm | 1 | Active |
| 332 | Zygo | HeNe/ tube (Collimated) | Class II | 632.8 nm | 1 | Active |
| 332 | Melles Griot | HeNe/Contained Tube | Class II | 632.8 nm | 1 | Active |
| 383 | Spectra Physics | HeNe | Class IIIa | 632.8 nm | 1 | Active |
| 384 | Melles Griot | HeNe | Class IIIB | 632.8 nm | 1 | Active |
| 324 | Melles Griot | HeNe | Class IIIB | 632.8 nm | 1 | Active |
| 332 | Melles Griot | HeNe/ Self contained tube | Class IIIB | 632.8 nm | 2 | Stored |
| 332 | Melles Griot | HeNe | Class IIIa | 633 nm | 1 | Stored |
| 324 | Coherent | HeNe | Class IIIa | 633 nm | 1 | Active |
| 383 | Spectra Physics | HeNe | Class IIIa | 633 nm | 2 | Active |
| 383 | Melles Griot | HeNe | Class IIIB | 633 nm | 1 | Active |
| 323 | Melles Griot | HeNe | Class IIIB | 633 nm | 1 | Active |
| 346 | JDS Uniphase | HeNe | Class IIIB | 633 nm | 1 | Active |
| 332 | HeNE | Gas | Class IIIB | 633 nm | 1 | Stored |
| 324 | Uniphase | HeNe/CW | Class IIIB | 633 nm | 2 | Active |
| 383 | Spectra Physics | HeNe | Class IIIa | 635 nm | 1 | Active |
| 324 | Sirah | Dye | Class IIIB | 282 nm | 1 | Active |
| 514 | PRA | DYE | ~2uJ | 400-900 nm | 1 | Stored |
| 326 | Continuum | Dye laser mix of rhodamine 590 and 610 | Class IV | 563-578 nm | 1 | Active |
| 383 | JDS | Nd:YAG | Class IIIB | 1.06 nm | 1 | Active |
| 384 | Spectra Physics | Nd:YAG,4th harmonic | Class IV | 266 nm | 1 | Active |
| 332 | JPL | Nd:YAG | Class IIIB | 532 nm | 1 | Active |
| 332 | Crystal Laser | Nd:YAG | Class IIIB | 532 nm | 1 | Stored |
| 383 | Crystal Laser | Nd:YAG | Class IIIB | 532 nm | 1 | Active |
| 332 | Spectra Physics | Nd:YAG | Class IV | 532/1064 nm | 1 | Active |
| 326 | Continuum | Nd:YAG | Class IV | 532 and 1064 nm | 1 | Active |
| 383 | Lightwave | Nd:YAG | Class IIIB | 1064 nm | 1 | Active |
| 332 | Lightwave | Nd:YAG | Class IIIB | 1064 nm | 1 | Active |
| 324 | JPL | Nd:YAG | Class IIIB | 1064 nm | 1 | Active |
| 332 | JPL (microchip) x 8 | Nd:YAG | Class IIIB | 1064 nm | 1 | Stored |
| 332 | Crystalaser | Nd:YAG | Class IIIB | 1064 nm | 1 | Stored |
| 332 | Crystalaser | Nd:YAG | Class IIIB | 1064 nm | 1 | Active |
| 332 | Lightwave | Nd:YAG/ Collimated | Class IIIB | 1064 nm | 1 | Active |

| Section | Laser Mfc | Lasing Media/Type | Power (Class) | Wavelength | Quantity | Status Active or Stored |
|---------|--------------------------------|---------------------------------|---------------|-------------------|----------|-------------------------|
| 383 | Lightwave | Nd:Yag | Class IIIB | 1300 nm | 2 | Active |
| 384 | Lightwave Electronics | Nd:YAG | Class IIIB | 1319 nm | 1 | Active |
| 346 | Lightwave | Nd:YAG | Class IIIB | 1319 nm | 2 | Active |
| 383 | Lightwave Electronics | Nd:YAG | Class IIIB | 1319 nm | 2 | Active |
| 383 | Lightwave | Nd:YAG | Class IIIB | 1319 nm | 2 | Active |
| 383 | Light Wave | Nd:YAG | Class IIIB | 1319 nm | 1 | Active |
| 324 | Spectra Physics | Nd:YAG(IV)/Pulsed | Class IV | 266 nm (1064,532) | 1 | Active |
| 324 | Spectra Physics | Nd:YAG(III) Pulsed | Class IV | 355 nm (1064,532) | 1 | Active |
| 324 | Spectra Physics | Nd:YAG(III)/Pulsed | Class IV | 355 nm (1064,532) | 1 | Active |
| 324 | Continuum | Nd:YAG(III)/Pulsed | Class IV | 355 nm (1064,532) | 1 | Active |
| 383 | Innolight | Nd:YAG, doubled, doubled output | Class IIIB | 532 and 1064 nm | 1 | Active |
| 332 | Lightwave | Nd:YAG ring | Class IV | 1064 nm | 1 | Stored |
| 332 | Lightwave | NdL YAG ring | Class IIIB | 1319 nm | 1 | Active |
| 332 | Lightwave | NdYAG/SS | Class IIIB | 1064 nm | 1 | Stored |
| 383 | Lightwave | Dd:YAG, doubled | Class IIIB | 532 nm | 1 | Stored |
| 332 | JPL | Nd:YVO | Class IIIB | 1064 nm | 1 | Active |
| 384 | Elektronik Laser Systems (ELS) | Yt:YAG | Class IV | 1.0-1.06 nm | 1 | Active |
| 323 | JPL | QC | Class IIIa | 6 nm | 1 | Active |
| 324 | Lambda Physik | Excimer | Class IV | 248 nm | 1 | Active |
| 324 | Lamda Physik | XeC1 Excimer | Class IV | 308 nm | 1 | Active |
| 514 | SP Frequency Doubler | LBO SHG Crystal | Class IV | 350-500 nm | 1 | Active |
| 332 | Spectra Physics | DPSS | Class IV | 532 nm | 1 | Stored |
| 332 | Coherent | Ti:Sapphire | Class IV | 720-1000 nm | 1 | Stored |
| 514 | SP Tsunami (Pico Ver) | Ti:Sapphire | Class IV | 690-1000 nm | 1 | Active |
| 383 | Lightwave Electronics | YAG NPRO | Class IIIB | 1319 nm | 1 | Active |
| 333 | Ortel | Plug in module | Class IIIa | 1330 nm | 1 | Stored |
| 346 | Lightwave | | Class IIIB | 1319 nm | 1 | Active |
| 346 | Laser-weld | | Class IV | 1319 nm | 1 | Active |

4 Conclusion

This project created new capabilities at JPL by setting up a semiconductor laser lab capable of laser lifetime and laser reliability tests. A number of deliverables as listed and highlighted above have been produced and the laser lab is now in use by a group working in the NuStar flight project.